

Modification of Eccentric Gaze-Holding

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Clear vision and accurate localization of objects in the environment are prerequisites for reliable performance of motor tasks. Space flight confronts the crewmember with a stimulus rearrangement that requires adaptation to function effectively with the new requirements of altered spatial orientation and motor coordination. Adaptation and motor learning driven by the effects of cerebellar disorders may share some of the same demands that face our astronauts. One measure of spatial localization shared by the astronauts and those suffering from cerebellar disorders that is easily quantified, and for which a neurobiological substrate has been identified, is the control of the angle of gaze (the "line of sight"). The disturbances of gaze control that have been documented to occur in astronauts and cosmonauts, both in-flight and postflight, can be directly related to changes in the extrinsic gravitational environment and intrinsic proprioceptive mechanisms thus, lending themselves to description by simple non-linear statistical models. Because of the necessity of developing robust normal response populations and normative populations against which abnormal responses can be evaluated, the basic models can be formulated using normal, non-astronaut test subjects and subsequently extended using centrifugation techniques to alter the gravitational and proprioceptive environment of these subjects. Further tests and extensions of the models can be made by studying abnormalities of gaze control in patients with cerebellar disease.

A series of investigations were conducted in which a total of 62 subjects were tested to: (1) Define eccentric gaze-holding parameters in a normative population, and (2) explore the effects of linear acceleration on gaze-holding parameters. For these studies gaze-holding was evaluated with the subjects seated upright (the normative values), rolled 45° to both the left and right, or pitched back 30 and 90°. In a separate study the further effects of acceleration on gaze stability was examined during centrifugation (+2 G_x and +2 G_z) using a total of 23 subjects. In all of our investigations eccentric gaze-holding was established by having the subjects acquire an eccentric target (±30° horizontal, ±15° vertical) that was flashed for 750 msec in an otherwise dark room. Subjects were instructed to hold gaze on the remembered position of the flashed target for 20 sec. Immediately following the 20 sec period, subjects were cued to return to the remembered center position and to hold gaze there for an additional 20 sec. Following this 20 sec period the center target was briefly flashed and the subject made any corrective eye movement back to the true center position. Conventionally, the ability to hold eccentric gaze is estimated by fitting the natural log of centripetal eye drifts by linear regression and calculating the time constant (τ_c) of these slow phases of "gaze-evoked nystagmus". However, because our normative subjects sometimes showed essentially no drift ($\tau_c = \infty$), statistical estimation and inference on the effect of target direction was performed on values of the decay constant $\theta = 1/\tau_c$, which we found was well modeled by a gamma distribution. Subjects showed substantial variance of their eye drifts, which were centrifugal in ~20 % of cases, and > 40% for down gaze.

Using the ensuing estimated gamma distributions, we were able to conclude that rightward and leftward gaze holding were not significantly different, but that upward gaze holding was significantly worse than downward ($p < 0.05$). We also concluded that vertical gaze holding was significantly worse than horizontal ($p < 0.05$). In the case of left and right roll, we found that both had a similar improvement to horizontal gaze holding ($p < 0.05$), but didn't have a significant effect on vertical gaze holding. For pitch tilts, both tilt angles significantly decreased gaze-holding ability in all directions ($p < 0.05$). Finally, we found that hyper-g centrifugation significantly decreased gaze holding ability in the vertical plane.

The main findings of this study are as follows: (1) vertical gaze-holding is less stable than horizontal, (2) gaze-holding to upward targets is less stable than to downward targets, (3) tilt affects gaze holding, and (4) hyper-g affects gaze holding. This difference between horizontal and vertical gaze-holding may be ascribed to separate components of the velocity-to-position neural integrator for eye movements, and to differences in orbital mechanics. The differences between upward and downward gaze-holding may be ascribed to an inherent vertical imbalance in the vestibular system. Because whole body tilt and hyper-g affects gaze-holding, it is implied that the otolith organs have direct connections to the neural integrator and further studies of astronaut gaze-holding are warranted.

Our statistical method for representing the range of normal eccentric gaze stability can be readily applied to normals who maybe exposed to environments which may modify the central integrator and require monitoring, and to evaluate patients with gaze-evoked nystagmus by comparing to the above established normative criteria.